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Yoon et al.

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(54) **MULTIFUNCTIONAL ORAL PROSTHETIC SYSTEM**

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A61C 13/00 (2006.01)
A61C 13/01 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61C 13/0024*** (2013.01); ***A61C 7/14*** (2013.01); ***A61C 13/01*** (2013.01); ***A61C 13/08*** (2013.01); ***A61C 19/04*** (2013.01); ***A61C 19/063*** (2013.01)

(58) **Field of Classification Search**
CPC ... A61C 19/04; A61C 19/063; A61C 13/0024; A61C 13/01; A61C 19/05; A61C 19/045;
(Continued)

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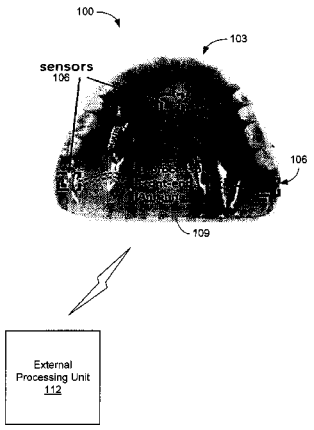
(57) **ABSTRACT**

Various methods and systems are provided for multifunctional denture systems. In one example, among others, a multifunctional oral prosthetic system includes an oral prosthetic device that may be located in an oral cavity. The oral prosthetic device includes a plurality of sensors and an
(Continued)



internal module in communication with the plurality of sensors. The internal module is configured to provide sensor data corresponding to at least one of the plurality of sensors to an external processing unit when located in an oral cavity.

21 Claims, 8 Drawing Sheets

(51) **Int. Cl.**

A61C 19/04	(2006.01)
A61C 7/14	(2006.01)
A61C 13/08	(2006.01)
A61C 19/06	(2006.01)

(58) **Field of Classification Search**

CPC A61C 7/07; A61C 7/14; A61B 5/1072; A61B 5/1075–1076; A61B 5/682; A61B 5/4542–4557; A61B 5/6885–6886; A61B 2562/0257

USPC 433/6, 27, 202.1, 215, 218, 229; 600/590, 587

See application file for complete search history.

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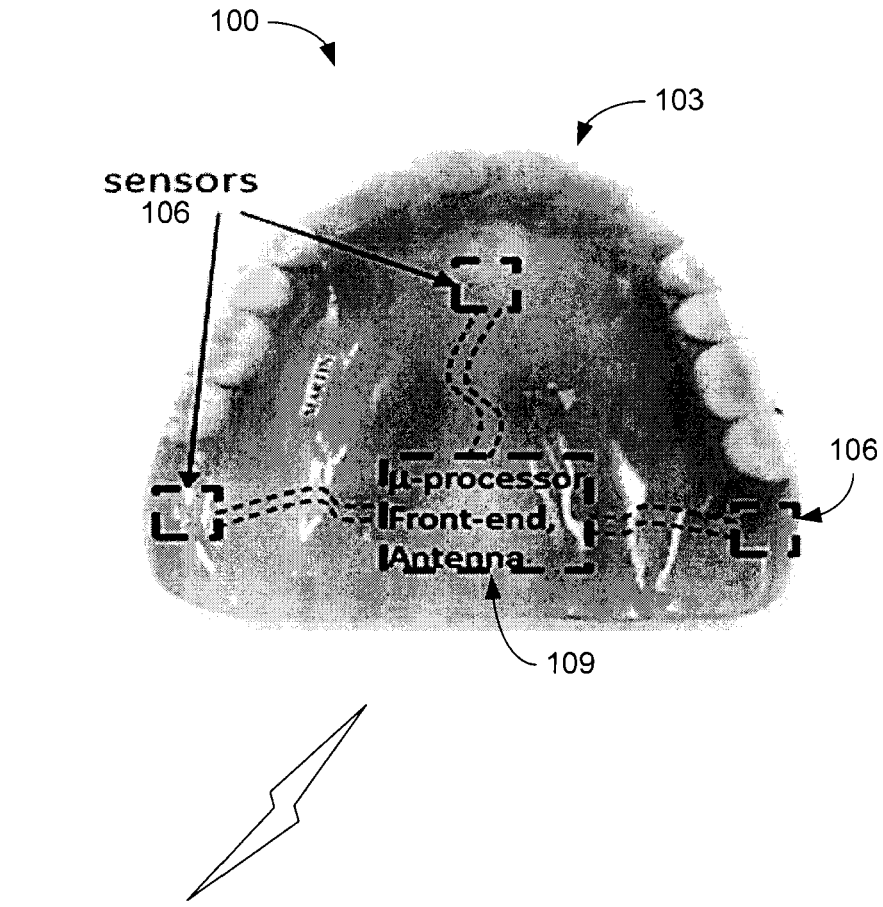
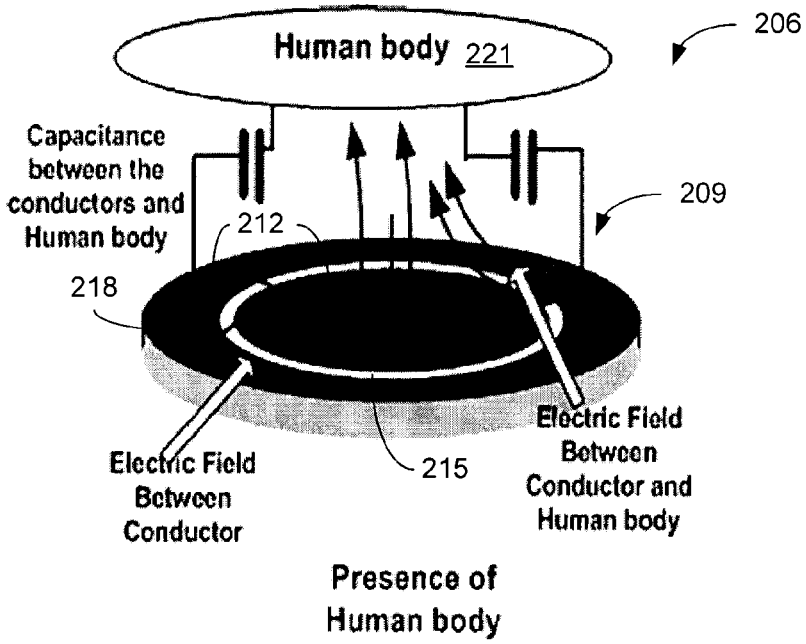
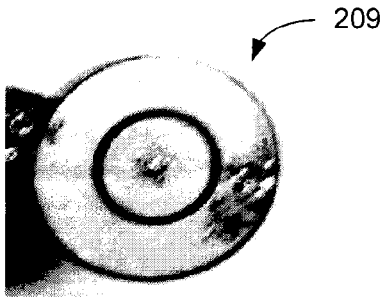

100
103
sensors
106
106
μ-processor
Front-end,
Antenna
109
External
Processing Unit
112

FIG. 1


Human body 221
206
Capacitance between the conductors and Human body
209
212
218
Electric Field Between Conductor
215
Electric Field Between Conductor and Human body
Presence of Human body

(a)


209

(b)

FIG. 2

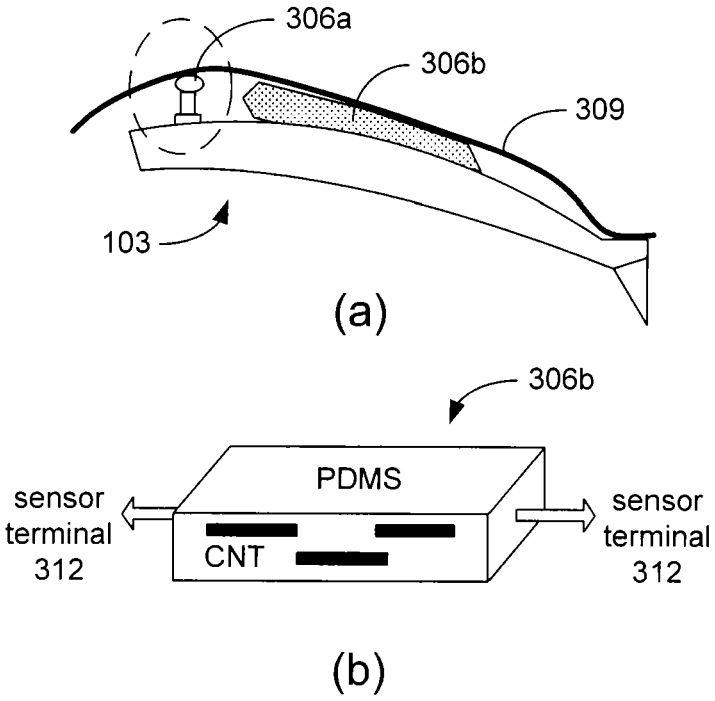

306a
306b
309
103
(a)
306b
PDMS
sensor terminal 312
CNT
sensor terminal 312
(b)

FIG. 3

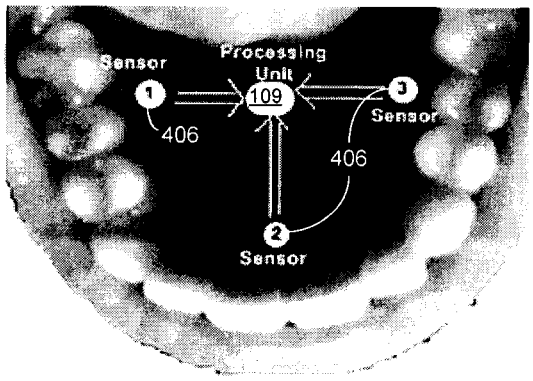

Sensor
1
Processing Unit
109
3
Sensor
406
406
2
Sensor

FIG. 4

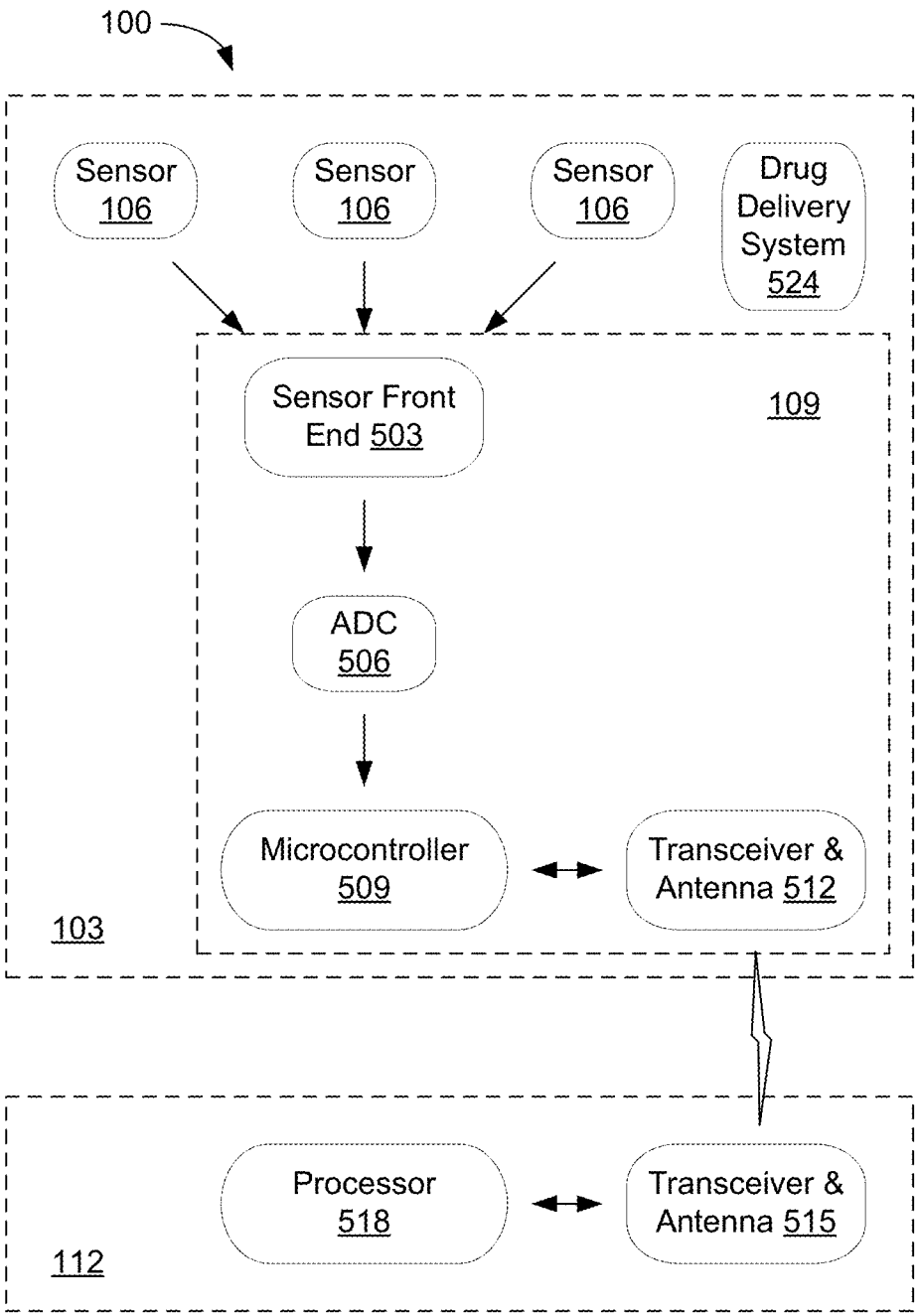

100
Sensor 106
Sensor 106
Sensor 106
Drug Delivery System 524
Sensor Front End 503
109
ADC 506
Microcontroller 509
Transceiver & Antenna 512
103
Processor 518
Transceiver & Antenna 515
112

FIG. 5

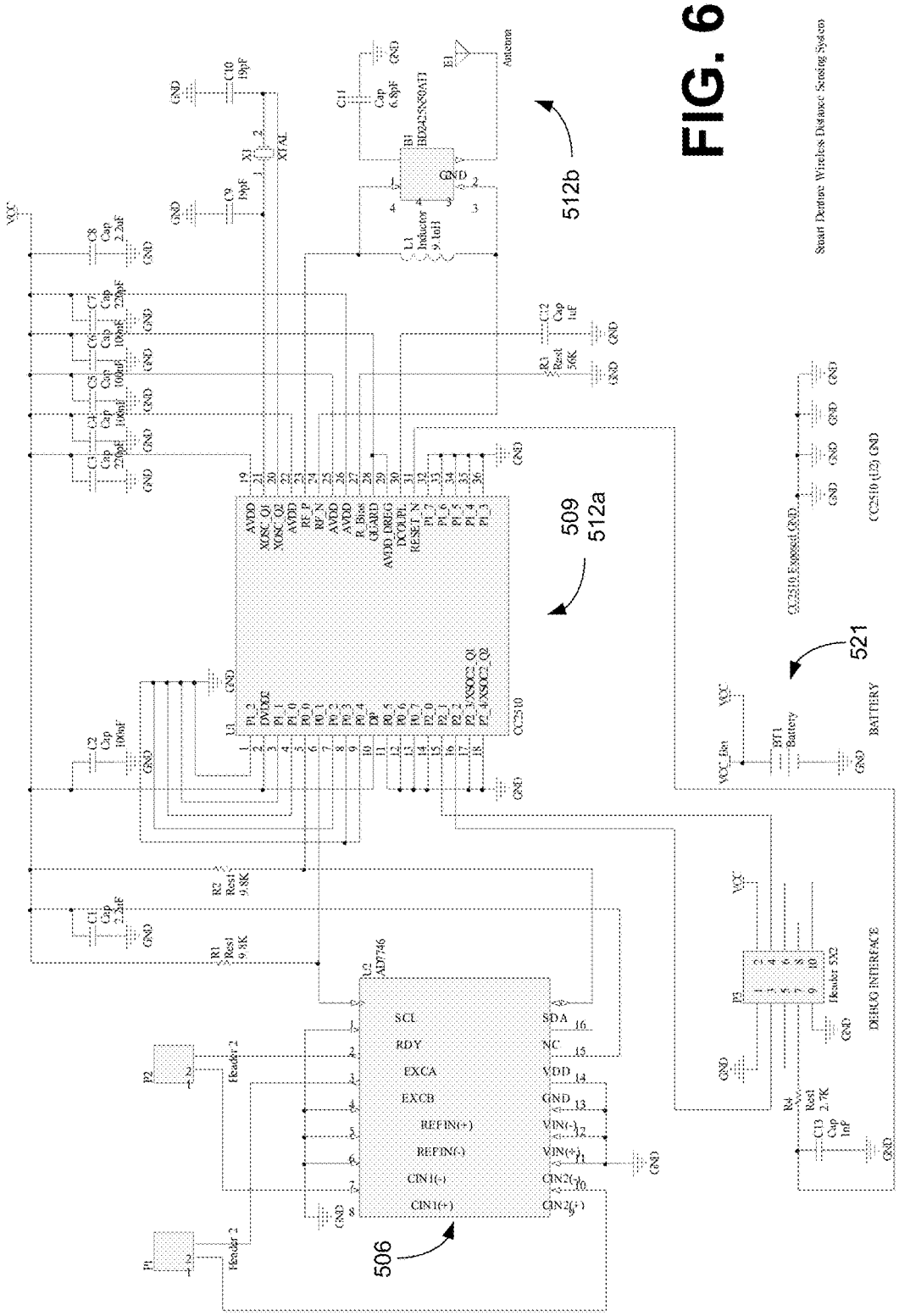
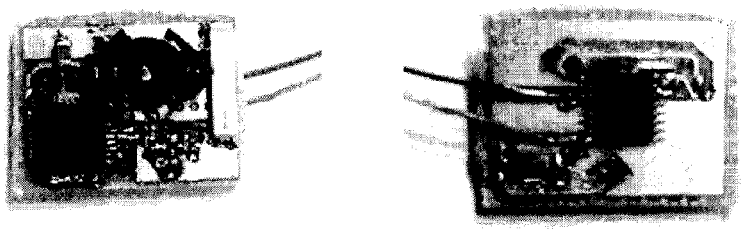

Smart Portiac Wireless Distance Sensing System
512b
509
512a
521
506
CC2510
ADT746
BATTERY
DEBUG INTERFACE
Header 2
Header 5X2
Antenna
XTAL
Inductor
Cap
Resl
Batt
Battery
Header 2
Header 5X2
Resl
Cap
Inductor
Antenna
XTAL
Batt
Battery
Header 2
Header 5X2
Resl
Cap
Inductor
Antenna
XTAL
Batt
Battery

FIG. 6



(a) (b)

FIG. 7

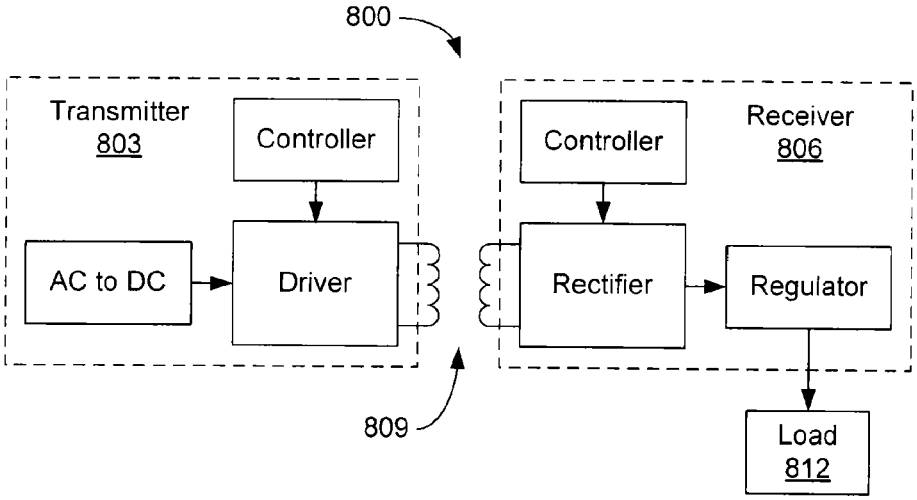

800
Transmitter
803
Controller
AC to DC
Driver
809
Controller
Receiver
806
Rectifier
Regulator
Load
812

FIG. 8

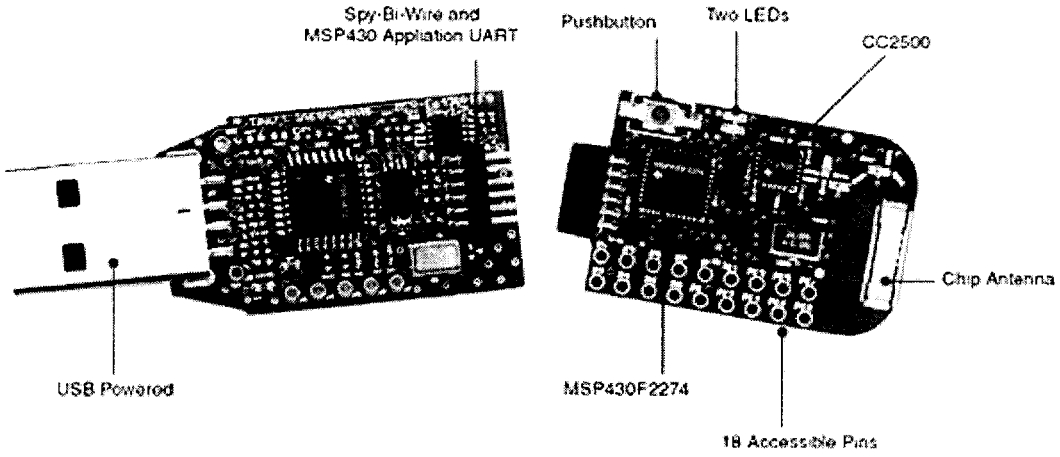

Spy-Bi-Wire and
MSP430 Appliation UART
Pushbutton
Two LEDs
CC2500
Chip Antenna
USB Powered
MSP430F2274
18 Accessible Pins

FIG. 9

Smart Denture System User Console v0.1
MSP430 Application UART (COM3)
78.7°F
Controller
20:13:19
3.6V
12.1mm
Sensor No. 1
0 Min
UF UNIVERSITY of FLORIDA
Connected

FIG. 10

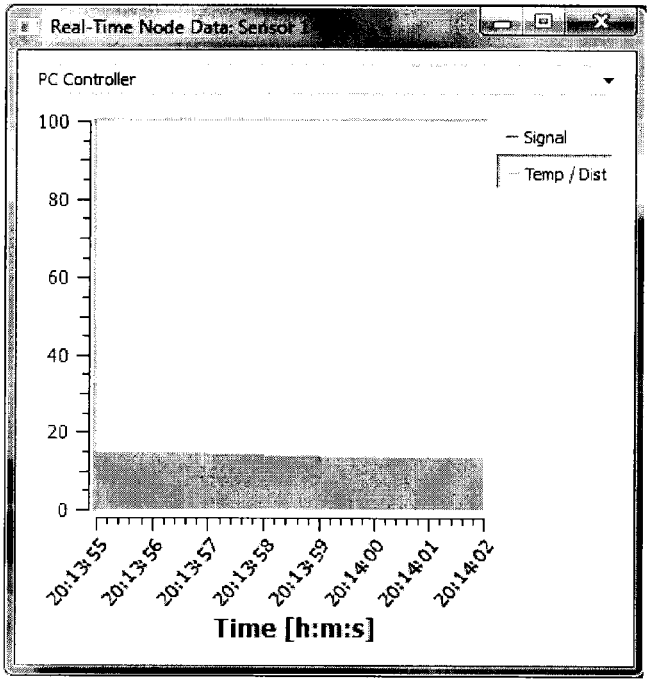

Real-Time Node Data: Sensor 1
PC Controller
100
80
60
40
20
0
Signal
Temp / Dist
20:13:55
20:13:56
20:13:57
20:13:58
20:13:59
20:14:00
20:14:01
20:14:02
Time [h:m:s]

FIG. 11

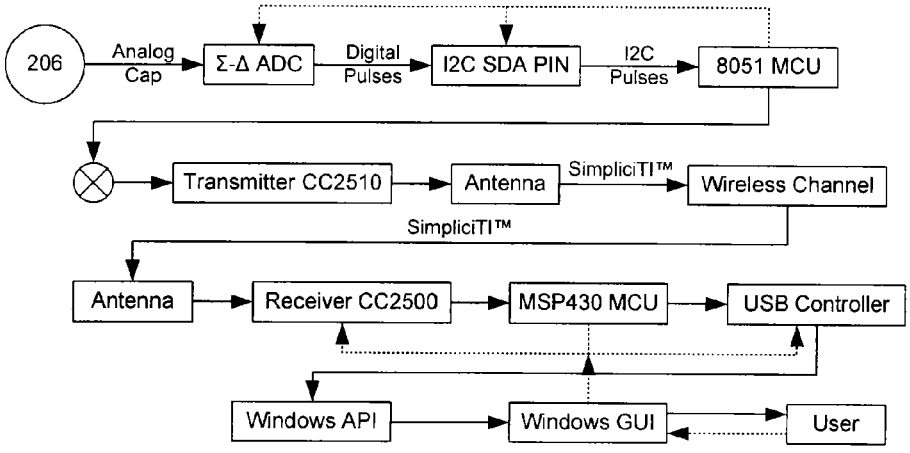

206
Analog Cap
Σ-Δ ADC
Digital Pulses
I2C SDA PIN
I2C Pulses
8051 MCU
Transmitter CC2510
Antenna
SimpliciTI™
Wireless Channel
SimpliciTI™
Antenna
Receiver CC2500
MSP430 MCU
USB Controller
Windows API
Windows GUI
User

FIG. 12

MULTIFUNCTIONAL ORAL PROSTHETIC SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is the 35 U.S.C. § 371 national stage of PCT Application No. PCT/US2012/057526, entitled "Multifunctional Oral Prosthetic System" and filed Sep. 27, 2012, which is hereby incorporated by reference in its entirety, and which claims priority to, and the benefit of, U.S. Provisional Application No. 61/540,183, filed Sep. 28, 2011, which is hereby incorporated by reference in its entirety.

BACKGROUND

Dental disease can result in damage to the gum tissue and ultimately in the loss of teeth. Often, prosthetic devices such as dentures are used to replace the missing teeth. The prosthetic device is supported by surrounding soft and hard tissues of the oral cavity. One of the most common problems with dentures is keeping them in place. Denture movement not only leads to discomfort, but may result in additional damage to the oral tissues. In general, dentists rely on tactile sensing to ascertain fit during in-office visits. However, such an invasive examination is hardly an accurate reflection of the environment the dentures are subjected to during the normal day-to-day routine of the wearer.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** is an example of a multifunctional denture system in accordance with various embodiments of the present disclosure.

FIGS. **2**(*a*) and **2**(*b*) are an example of a capacitive displacement sensor of the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIGS. **3**(*a*) and **3**(*b*) are examples of strain gauge displacement sensors of the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIG. **4** is an example of the placement of displacement sensors of FIGS. **2** and **3** in the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIG. **5** is a graphical representation of an example of the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIG. **6** is a schematic diagram illustrating an example of the multifunctional denture system of FIG. **5** in accordance with various embodiments of the present disclosure.

FIGS. **7**(*a*) and **7**(*b*) are an implementation of the multifunctional denture system of FIG. **6** in accordance with various embodiments of the present disclosure.

FIG. **8** is a graphical representation of an example of a wireless power delivery system for use in the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIG. **9** is an example of a transceiver and antenna used in an external processing unit of the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIGS. **10** and **11** are examples of a graphical user interface shown on a display (e.g., a computer screen) of the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

FIG. **12** is an example of the data flow within the multifunctional denture system of FIG. **1** in accordance with various embodiments of the present disclosure.

DETAILED DESCRIPTION

Disclosed herein are various embodiments of systems and methods related to multifunctional denture systems. Reference will now be made in detail to the description of the embodiments as illustrated in the drawings, wherein like reference numbers indicate like parts throughout the several views.

In situ monitoring of changes in the conditions such as distance, pressure, and movement allows for evaluation of an individual's oral condition over time. In addition, saliva can provide information not only on the state of the oral cavity, but also on the systemic health of the individual. Other in situ monitoring may also be used to evaluate and identify speech patterns and/or impediments. Advancement of microelectronic and sensor technologies can provide implantable or minimally invasive biomedical devices for oral applications. Additionally, developments in nanotechnology and microelectromechanical system (MEMS) technology have miniaturized sensors with increased sensitivity and selectivity, providing the ability to monitor a wide range of conditions. This disclosure presents a multifunctional denture system that includes an integrated system capable of multiplexed detection and in situ monitoring for diagnostics and prognostics without invasive examination.

Referring to FIG. **1**, shown is an example of a multifunctional denture system **100**. The multifunctional denture system **100** includes a denture **103** (full or partial) that is a prosthetic device constructed to replace missing teeth and which is supported by surrounding soft and hard tissues of the oral cavity. The denture **103** (full or partial) includes one or more sensor(s) **106** such as, e.g., displacement sensors to measure the distance (or gap) between the denture and oral tissue; stress/strain sensors to gauge denture dislocation, pressure, and movement; temperature sensors to survey the oral cavity environment for assessment of oral and physiologic system health; and/or various chemical sensors and biomedical sensors to monitor, e.g., pH, glucose, or enzymes and for diagnostics and prognosis of clinical problems such as, e.g., oral diseases, HIV, cancer, and diabetes. Nanotechnology and microelectromechanical system (MEMS) technology have driven the development of sensors **106** with increased sensitivity and selectivity. The sensors **106** are communicatively coupled to an internal module **109** for data and signal processing. The internal module **109** is configured to gather information from the sensors **106** and transmit the gathered data to an external processing unit **112**.

The internal module **109** includes, e.g., a microprocessor to process data from the sensors **106**. The internal module **109** may include a sensor front end and/or an analog-to-digital converter (ADC) for obtaining data from the sensors **106** and providing the data to the microcontroller in the appropriate format. The internal module **109** may also include a transceiver and antenna for wireless data transmission (e.g., a radiofrequency, microwave, or other appro-

priate transmission) of the data to the external processing unit **112** for further processing and evaluation. The external processing unit **112** may be a computing device configured to render for display the data obtained from the internal module **109**. In the example of FIG. **1**, the sensors **106** and the internal module **109** of the multifunctional denture system **100** are embedded in a full denture **103**. In other embodiments, sensors **106** may be affixed to a surface of the denture **103**, orthodontic braces, or dental veneers. In other implementations, the denture **103** may be a partial denture.

A variety of sensors **106** may be used in the multifunctional denture system **100**. Referring to FIG. **2**(*a*), shown is a graphical representation of an example of a capacitive displacement sensor **206** that may be included in the denture **103**. The capacitive displacement sensor **206** can include a gap capacitor **209** having two co-planar plates **212** separated by a gap **215**. In the example of FIG. **2**(*a*), the two co-planar plates **212** are concentric. FIG. **2**(*b*) is a picture of a concentric gap capacitor. When a voltage is applied to the two co-planar plates **212**, a fringing electric field **218** is established at the gap **215**. When an electric conductor **221** approaches the co-planar conductors **212**, the fringing electric field **218** at the gap **215** is disrupted or distorted by the conductor **221**. The capacitance of the gap capacitor **209** changes as a function of the distance between the electric conductor **221** and the co-planar plates **212**. Since the human body is considered a good conductor **221**, the detection of capacitance change can be used as a distance sensing mechanism. The gap capacitor **209** may be embedded in denture **103** to detect the distance between the denture **103** and the oral tissue **221**. To increase the sensitivity of the gap capacitor **209**, an interdigitated capacitor design or a fractal capacitor design may be used.

Referring next to FIGS. **3**(*a*) and **3**(*b*), shown are examples of strain gauge sensors **306** that may be included in the denture **103**. A strain gauge is used to measure the elongation or contraction of an object. When a denture **103** is in contact with the oral tissue **309**, a strain gauge sensor **306** can be used for the detection of the dislocation, pressure, and movement of the denture **103** relative to the oral tissue **309**. When the Young's modulus of the strain gauge material and the measured strain are known, the stress may be calculated using $\sigma=E\cdot\varepsilon$, where σ is the stress, E is the Young's modulus, and ε is the strain. In general, a mouth can generate a pressure in the range of about 10 lbs. to about 200 lbs. (i.e., 2000 kPa). With this in mind, a strain gauge sensor **306** should withstand this pressure range while being capable of measuring displacement in the range of about 50 μm to about 500 μm.

FIG. **3** includes examples of two different strain gauge sensors **306***a* and **306***b*. The first strain gauge sensor **306***a* uses a match stick type of strain gauge such as, e.g., a SCP 100 pressure sensor (120 kPa range) from VTI Technologies and a pressure membrane. In the example of FIG. **3**(*a*), the match stick strain gauge **306***a* contacts the oral tissue **309** along the mouth ceiling. Displacement of the denture **103** distorts the match stick strain gauge generating a signal that can be correlated to the displacement. The second strain gauge sensor **306***b* utilizes an engineered composite material made of polydimethylsiloxane (PDMS) and carbon nanotubes (CNT) that is positioned between the denture **103** and the tissue **309** of the oral cavity. FIG. **3**(*b*) is a graphical representation of the composite material strain gauge **306***b*. Distortion of the PDMS/CNT composite material produces a detectable change in the output between sensor terminals **312** that can be correlated to the displacement of the denture **103**. To increase the sensing accuracy of denture displacement, data from a plurality of displacement sensors **206**/**306** located in the denture **103** may be processed. FIG. **4** shows an example of the placement of three displacement sensors **406** (e.g., displacement sensors **206**/**306**) about the denture **103** to obtain accurate displacement indications.

The denture **103** may also include other sensors **106** such as, e.g., temperature sensors and/or chemical and biomedical sensors for monitoring the oral cavity environment. Saliva is a complex oral fluid that serves important functions in maintaining homeostasis of the oral cavity system. Many of the enzymes, hormones, antibodies, antimicrobial constituents, and cytokines in the saliva enter from the blood. This means saliva can provide information not only on the state of oral health, but also on systemic health. For example, biomarkers for oral diseases or other medical diseases such as, e.g., HIV, cancer, and diabetes may be detected in saliva. For instance, glucose sensing may be used for monitoring diabetes.

Referring next to FIG. **5**, shown is an example of a sensor network of a multifunctional denture system **100**. Signals received from one or more sensors **106** mounted in denture **103** may be processed by a sensor front end **503** (e.g., a MUX) and converted by an analog-to-digital converter (ADC) **506** for processing by a microcontroller unit (MCU) **509**. The MCU **509** can provide the acquired sensor data from the denture **103** to an external processing unit **112** through a transceiver and antenna **512**. In some implementations, the internal module **109** may include memory to store sensor data for subsequent transmission to the external processing unit **112** and/or code or instructions that may be executed by the microcontroller **509**. The external processing unit **112** includes a transceiver and antenna **515** that receives the transmitted sensor information and provides it to a processor **518** for analysis and processing. Transmission between the denture **103** and the external processing unit **112** may be over, e.g., a 2.4 GHz communication link.

For example, distance information may be obtained by a capacitive sensor **206** (FIG. **2**), which is transmitted to an ADC **506** such as, e.g., an AD7746 from Analog Devices. The digitalized signals are fed into a MCU **509** for data processing before being transmitted to a transceiver **512**. A CC2510 (Texas Instruments Inc.) may be used as an integrated microcontroller unit and transceiver for more compact and power efficient system implementation. The signal is transmitted over a wireless channel (or link) through a chip antenna **512** and received by a receiver (e.g., CC2500 by Texas Instruments Inc.) and antenna **515**. The signal is transferred to a computer or ether processor circuit **518**, where it may be rendered and displayed on a screen or display via a graphical user interface (GUI) such as illustrated in FIG. **10**. By appropriate processing, the distance information may be extracted from the sensor data and presented on the screen in real time as illustrated in FIG. **11**.

Since the sensor network is embedded in the denture **103** where space is limited, the physical and electrical requirements can be stringent. An example of the specifications of the sensor network circuit is listed in TABLE 1. In some embodiments, the sensor network circuit may be implemented using a very large scale integration (VLSI) integrated circuit (IC) approach, which may reduce the size to one tenth the size of the original circuit board. The whole sensor network circuit and micro/nanosensors may be realized in a size scale of a few millimeters or micrometers.

TABLE 1

Item	Specification
Board size	15 mm × 10 mm × 2 mm (L × W × T)
Power supply voltage	3 V ± 0.3 V
Current consumption	17.7 mA (active mode)
Precision	25 μm
Measurement range	15 mm
Carrier frequency	ISM 2.4 GHz Band
Max. wireless channel distance	2 meters (may vary)
Measurement duration	20 min. (typical)
Weight	5.19 g (bare board and sensor, battery exclusive)
Recharge	"Qi" Compatible wireless recharge

Referring to FIG. **6**, shown is a schematic diagram of an example of an implemented circuit. The example of FIG. **6** includes two main parts: an AD7746 (U2) comprises the sensing front end circuit **506** which receives a capacitance value from, e.g., a capacitive sensor **206** (FIG. **2**) and produces an analog voltage output, and subsequently converts it into a digital signal; a CC2510 (U1) comprises the integrated microcontroller **509** and transceiver **512***a*. AD7746 is a sigma-delta (Σ-Δ) converter which has a capacitance sensing range of about ±4.096 pF with an accuracy of about 4 fF. Also, the example of FIG. **6** includes a built-in temperature sensor with a resolution of 0.1 degree centigrade on board. The digitized capacitance information is transferred to CC2510 (microcontroller **509** and transceiver **512***a*) for further signal processing and signal modulation for wireless transmission through antenna **512***b*.

The CC2510 comprises an enhanced **8051** core MCP **509** as well as an ISM band transceiver **512***a*. Between the AD7746 sensing front end circuit **506** and the CC2510 microcontroller **509**/transceiver **512***a*, an I2C communication protocol may be used. The digitized distance information is modulated in the CC2510 microcontroller **509** and then transmitted to the free space wireless channel (or link) via a chip antenna **512***b*. FIG. **7** shows (a) front and (b) back views of a prototype of the circuit of FIG. **6**. While the example of FIGS. **7**(*a*) and **7**(*b*) uses off-chip components for the proof of concept, the circuit may be implemented using customized VLSI circuits. The whole electronic circuit and micro/nano sensors may be realized in a size scale of a few millimeters or micrometers.

Power for the circuitry may be provided by a power source such as, e.g., a battery **521** (FIG. **6**). Considering the sensor network of a multifunctional denture system **100** of FIG. **6** is included in the denture **103**, it may be desirable to avoid having to replace the battery **521**. A wireless power delivery system may be used to supply power to a rechargeable battery **521** through inductive coupling. Referring to FIG. **8**, shown is a graphical representation of a wireless power delivery system **800**. Power is delivered between a transmitter **803** and a receiver **806** by inductive coupling between the antennas **809**. The delivered power may then be regulated for delivery to a load **812** such as the sensor network. For example, a spiral antenna **809** may be used for near field power coupling and BQ500110 and BQ51013 ICs from Texas Instruments Inc. may be used as the transmitter **803** and the receiver **806**, respectively. Since the BQ500110 and BQ51013 ICs are highly integrated chips, nearly no peripherals are required on the receiver side for power collection, making it ideal for device size reduction.

In addition to the sensor network of FIG. **5**, the multifunctional denture system **100** may also include drug delivery system **524** that may interface with the internal module **109**. The denture **103** may include a sealed reservoir for storing the drug and a dispenser for supplying a defined amount of drug to the oral cavity. In some cases, a plurality of reservoirs may be included with one or more dispensers for delivery of one or more drugs and/or dosages. The internal module **109** may control timing and/or dosage for the delivery system.

Referring back to FIG. **5**, the external processing unit **112** includes a transceiver and antenna **515** that receives the transmitted sensor information from the transceiver and antenna **512** and provides it to a processor **518** for analysis and processing. For example, a transceiver and antenna circuit **515** including an MSP430 IC and a CC2500 IC by Texas Instruments Inc. may be provided in, e.g., a USB dongle shape as shown in FIG. **9**. The transceiver/antenna circuit **515** may be configured to be plugged into the external processing unit **112** such as, e.g., a computing device (or PC) through a USB connector. Transmission between the denture **103** and the external processing unit **112** may be over, e.g., a 2.4 GHz communication link, a 403-405 MHz medical implant communication service (MICS) band, or other industry science medicine (ISM) bands including, e.g., 433 MHz, 915 MHz, and 5.8 GHz.

Communications between the denture **103** and external processing unit **112** (FIGS. **1** and **5**) may be carried out using a variety of communication protocols such as, e.g., SimpliciTI™. SimpliciTI™ is a simple communication protocol especially designed for low cost and small scale network. Since it contains a device switch to change between sleep and active states, it is also known as a low power consuming protocol. Also, certain flexibility is offered and allowing use with multiple network topologies such as peer-to-peer or star network including a central access point, which can be used in the multifunctional denture system **100**. The star network configuration allows the external processing unit **112** to communicate with the internal module **109** of one or more denture(s) **103**. Two kinds of devices may be used in a star network: a data hub or access point (e.g., a transceiver/antenna circuit **515** of the external processing device) and end devices (e.g., dentures **103**). Usually, there is only one access point in a network and it is always on and in charge of network token management (e.g., dentures **103** joining or leaving the network). The access point manages the functionality of end devices such as link listening and receiving. More than one end device can coexist in a network, which are all managed by a single access point.

After an initialization procedure, an end device (e.g., internal module **109** of a denture **103**) will transmit a join message to the access point (e.g., transceiver/antenna circuit **515**) with a network token in the message. If the join message is identical with that of the access point, an address will be given to the end device by the access point and a communication link is established. To save energy, the end device may enter a sleep state after a data package is transmitted to the access point. For example, after transmitting sensor data to the external processing device **112**, the internal module **109** of a denture **103** may sleep for 100 machine cycles before waking up to see if a message or command is waiting on the access point of the external processing unit **112**. If there is, the end device (e.g., internal module **109** of denture **103**) will turn active and function as desired. Otherwise, the end device enters another sleep period. During the sleep period of the end device, the access point is allowed to process data obtained from the end device and/or communicate with another end device. Since the end device only consumes several micro amperes of currents,

this method saves a significant amount of energy in comparison to the case where all end devices are constantly active.

This may be further described in the context of the multifunctional denture system **100** of FIG. **5**. Analog sensor data is obtained from one or more sensors **106** and converted by an ADC **506**. Where an AD7746 is used as the ADC **506** (FIG. **6**), only an I2C communication protocol is supported. The I2C protocol was first introduced by Philips for use in microcontroller data acquisition. To obtain data from, e.g., a capacitive displacement sensor **206** (FIG. **2**), three steps can be performed on AD7746: (1) reset the chip then wait for 200 μs; (2) write proper configuration information to corresponding registers such as excitation voltage, measurement frequency, capacitance chop, etc.; and (3) read from corresponding registers where the measured capacitance is stored. The acquired sensor data are then sent to the microcontroller **509** and transceiver **512** (e.g., the CC2510 microcontroller **509**/transceiver **512***a* of FIG. **6**) where they are modulated and transmitted to the access point according to the SimpliciTI™ protocol. This may be further connected to a mobile system such as, e.g., a smart phone, a PDA, a tablet (PC) device, a portable computer, or other mobile device to continuously monitor health conditions for patients, realizing "mHealth" (mobile health), a term used for the practice of medicine and public health supported by mobile devices. The mobile device may execute appropriate applications (apps) to implement the mHealth monitoring system.

At the external processing unit **112**, a transceiver/antenna **515** such as, e.g., the MSP430-CC2500 based USB dongle of FIG. **9** is programmed based on SimpliciTI requirements and works as the access point of the network. Sensor data are received through the transceiver/antenna **515** and processed by the processor **518** of the external processing unit **112** such as, e.g., a PC for a windows graphical user interface (GUI) to display. An example of a display rendered by a graphics application executed by the processor **519** of the external processing unit **112** is shown in FIG. **10**. Temperature, displacement, and other indications may be provided by the GUI including time when the data was obtained.

Real time sensor data may also be rendered for display by the external processing unit **112**. Statistic curves may also be rendered for display to provide sensor data such as temperature, displacement, etc. over a period of time. For example, FIG. **11** illustrates a displacement curve, where the x-axis shows time in seconds and the y-axis shows the distance between the denture **103** and the oral tissue **309** (FIG. **3**). The curve may be for a single sensor **106** or a combination of sensors **106**. The sampling time may be increased or decreased as needed or desired.

Referring to FIG. **12**, shown is an example of the overall data flow within a multifunctional denture system **100**. While the example of FIG. **12** is with respect to a capacitive displacement sensor **206** (FIG. **2**), it can be extended to other types of sensors as can be understood. A capacitance signal is first obtained from a capacitive displacement sensor **206** and digitalized by an ADC **506** (e.g., AD7746). The digitalized capacitance information is then sent to microprocessor **509**/transceiver **512***a* (e.g., CC2510) via I2C protocol. The CC2510 chip modulates the capacitance information and transmits the modulated information to the wireless channel via the transmitter antenna **512***b*. The procedure is guided by the SimpliciTI™ protocol. A transceiver/antenna **515** (e.g., MSP430-CC2500 USB dongle) works as the access point of the external processing unit **112**. The transmitted data are received by the receiver antenna of the USB dongle, processed, and sent to the processor **518** of the external processing unit **112** for further processing. The data may then be displayed in a Windows GUI operating within the Windows API. Both real time and statistic data may be made available to the user. The Windows GUI may also allow the user to configure operation of the internal module **109** of the denture **103** through the transceivers and antennas **512** and **515**.

For example, to convert the capacitance value to distance, it may be necessary to calibrate the multifunctional denture system **100**. For instance, a linear relationship may be assumed between the capacitance and distance (or displacement) values for small distances within, e.g., 15 mm. An accurate distance stage is set to a known distance and the corresponding capacitance measurement is recorded. By measuring multiple data points corresponding to different distances, the relationship between distance and capacitance measurements can be determined as, e.g., a curve and/or an equation. This relationship may then be used to map a measured capacitance value into its corresponding distance (or displacement) information.

When used, the calibration of the multifunctional denture system **100** may be performed as follows: each sensor **106** (FIG. **1**) is pre-calibrated in, e.g., a lab and an initial relationship (e.g., an equation) is obtained. Then the denture **103** (FIG. **1**) with the embedded sensors **106** is installed in a patient. When the denture **103** is in full contact as determined by a health care professional and/or the patient, sensor measurements or data are obtained and the measurement point is recorded as zero. This zero point information is then used to further correct errors in the initial mapping relationship. Thus, variations from patient to patient may be accounted for. Multiple zero point calibrations might be necessary and multiple measurement results could be averaged to ensure repeatability of the measurements.

Briefly described, one embodiment, among others, comprises a multifunctional oral prosthetic system. The multifunctional oral prosthetic system includes an oral prosthetic device. The oral prosthetic device can include a plurality of sensors and an internal module in communication with the plurality of sensors. The internal module may be configured to provide sensor data corresponding to at least one of the plurality of sensors to an external processing unit when located in an oral cavity. The internal module may be configured to obtain analog signals from each of the plurality of sensors. The plurality of sensors may include a displacement sensor configured to provide an indication of displacement of the oral prosthetic device within the oral cavity, a temperature sensor, a chemical sensor configured to provide an indication of pH level, or a biomedical sensor configured to provide an indication of glucose level. The oral prosthetic device may include a drug delivery system. The drug delivery system may comprise a dispenser configured to supply a defined dosage of a drug to the oral cavity. The internal module may include an analog-to-digital converter (ADC), a microprocessor, and a transceiver embedded in the oral prosthetic device.

The multifunctional oral prosthetic system may comprise the external processing unit configured to obtain the sensor data from the internal module. The external processing unit may be configured to process the obtained sensor data to determine a condition of the oral cavity. The condition of the oral cavity may be a biomarker for an oral disease. The external processing unit may be configured to provide an indication of the condition of the oral cavity through a graphical user interface (GUI). The external processing unit may be configured to process the obtained sensor data to determine a condition of the oral prosthetic device. The

condition of the oral prosthetic device may be displacement within the oral cavity. The external processing unit may be configured to provide an indication of the condition of the oral prosthetic device through a graphical user interface (GUI). The denture may comprise a wireless power delivery system. The oral prosthetic device may be a partial denture, a full denture, orthodontic braces, or a dental veneer. The internal module may be configured to communicate with the external processing unit over a wireless channel. The external processing unit may be a cell phone configured to implement a mobile health monitoring system, a PDA configured to implement a mobile health monitoring system, a tablet device configured to implement a mobile health monitoring system, or a portable computer configured to implement a mobile health monitoring system.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

It should be noted that ratios, concentrations, amounts, and other numerical data may be expressed herein in a range format. It is to be understood that such a range format is used for convenience and brevity, and thus, should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. To illustrate, a concentration range of "about 0.1% to about 5%" should be interpreted to include not only the explicitly recited concentration of about 0.1 wt % to about 5 wt %, but also include individual concentrations (e.g., 1%, 2%, 3%, and 4%) and the sub-ranges (e.g., 0.5%, 1.1%, 2.2%, 3.3%, and 4.4%) within the indicated range. The term "about" can include traditional rounding according to significant figures of numerical values. In addition, the phrase "about 'x' to 'y'" includes "about 'x' to about 'y'".

The invention claimed is:

1. A multifunctional oral prosthetic system, comprising:

an oral prosthetic device comprising an upper portion configured to align with a roof of an oral cavity of a wearer, the upper portion of the oral prosthetic device including:

a plurality of sensors embedded in the upper portion including a displacement sensor configured to provide at least one sensor value that corresponds to at least one displacement distance between the upper portion of the oral prosthetic device and the roof of the oral cavity while being worn by the wearer, where the displacement sensor is fixed into a section of the upper portion of the oral prosthetic device that is adjacent to the roof of the oral cavity when worn by the wearer; and

an internal module in communication with the plurality of sensors, the internal module configured to provide sensor data corresponding to at least one of the plurality of sensors to an external processing unit when located in an oral cavity, the sensor data comprising the at least one sensor value, where the external processing unit determines the at least one displacement distance between the upper portion of the oral prosthetic device and the roof of the oral cavity using the at least one sensor value.

2. The multifunctional oral prosthetic system of claim **1**, wherein the internal module is further configured to obtain analog signals from each of the plurality of sensors.

3. The multifunctional oral prosthetic system of claim **1**, wherein the oral prosthetic device is a denture system that is removable from the oral cavity.

4. The multifunctional oral prosthetic system of claim **1**, wherein the plurality of sensors includes a chemical sensor configured to provide an indication of pH level.

5. The multifunctional oral prosthetic system of claim **1**, wherein the plurality of sensors includes a biomedical sensor configured to provide an indication of glucose level.

6. The multifunctional oral prosthetic system of claim **1**, wherein the oral prosthetic device further comprises a drug delivery system in communication with the internal module, where a drug delivery dosage is controlled by the internal module.

7. The multifunctional oral prosthetic system of claim **6**, wherein the drug delivery system comprises a dispenser configured to supply one of a plurality of drugs to the oral cavity.

8. The multifunctional oral prosthetic system of claim **1**, wherein the internal module includes an analog-to-digital converter (ADC), a microprocessor, and a transceiver embedded in the upper portion of the oral prosthetic device.

9. The multifunctional oral prosthetic system of claim **1**, further comprising the external processing unit configured to obtain the sensor data from the internal module.

10. The multifunctional oral prosthetic system of claim **9**, wherein the external processing unit is configured to process the obtained sensor data to determine a condition of the oral cavity.

11. The multifunctional oral prosthetic system of claim **10**, wherein the condition of the oral cavity is based at least in part upon evaluation of a biomarker for an oral or other medical disease.

12. The multifunctional oral prosthetic system of claim **10**, wherein the external processing unit is further configured to provide an indication of the condition of the oral cavity through a graphical user interface (GUI).

13. The multifunctional oral prosthetic system of claim **9**, wherein the external processing unit is configured to process the obtained sensor data to determine a condition of the oral prosthetic device.

14. The multifunctional oral prosthetic system of claim **13**, wherein the condition of the oral prosthetic device is indicated by a displacement curve determined using the at least one displacement distance between the upper portion of the oral prosthetic device and the roof of the oral cavity.

15. The multifunctional oral prosthetic system of claim **13**, wherein the external processing unit is further configured to provide an indication of the condition of the oral prosthetic device through a graphical user interface (GUI).

16. The multifunctional oral prosthetic system of claim **1**, wherein the oral prosthetic device further comprises a wireless power delivery circuit configured to supply power to the oral prosthetic device that was received wirelessly from a transmitting source.

17. The multifunctional oral prosthetic system of claim **1**, wherein the oral prosthetic device is a partial denture, a full denture, or orthodontic braces.

18. The multifunctional oral prosthetic system of claim **1**, wherein the internal module is configured to communicate with the external processing unit over a wireless channel.

19. The multifunctional oral prosthetic system of claim 18, wherein the external processing unit is a cell phone, a PDA, a tablet, or a portable computer.

20. The multifunctional oral prosthetic system of claim 18, wherein the external processing unit is configured to implement a mobile health monitoring system via an application executed by the external processing unit.

21. A multifunctional oral prosthetic system, comprising:

an oral prosthetic device comprising an upper portion configured to align with a roof of an oral cavity of a wearer, the upper portion of the oral prosthetic device including:

a plurality of sensors embedded in the upper portion including a displacement sensor configured to provide at least one sensor value that corresponds to at least one displacement distance between the upper portion of the oral prosthetic device and the roof of the oral cavity while being worn by the wearer, wherein:

the displacement sensor is fixed into a section of the upper portion of the oral prosthetic device that is adjacent to the roof of the oral cavity when worn by the wearer, and

the displacement sensor is a capacitive displacement sensor, where a capacitance of the capacitive displacement sensor varies as a function of the distance between the upper portion of the oral prosthetic device from the roof of the oral cavity; and

an internal module in communication with the plurality of sensors, the internal module configured to provide sensor data corresponding to at least one of the plurality of sensors to an external processing unit when located in an oral cavity, the sensor data comprising the at least one sensor value, where the external processing unit determines the at least one displacement distance between the upper portion of the oral prosthetic device and the roof of the oral cavity using the at least one sensor value.

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